SPACE TIMES

OzGrav
July 2022

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Welcome

Dear colleagues,

Welcome to another edition of Space Times! This month we're preparing for the final part of the selection process for the 2023 ARC Centres of Excellence in which OzGrav was fortunate enough to join 16 other potential centres for support from 2023-2030. Our intrepid 6-person interview team will be grilled for an hour in early August about the exciting science we'd pursue if selected.

OzGrav will be championing six key projects: OPTIMISATION concerns maximising the yield of the current generation detectors; DETECTIONS will discover new sources of GWs and search for electromagnetic counterparts; GRAVITY will explore the black holes of general relativity and use pulsars to test Einstein's theory; EXTREME MATTER will explore the structure of neutron stars; and COSMOS will help define the age and mass of the Universe. Finally, the FUTURE TECH key project will maximise Australia's role in future detectors in both Space and on the ground. By 2030 we will have entrenched Australia's role in this discipline, hopefully for decades. As with this Centre, many supporting activities will feature ranging from career development to tech transfer and public outreach and education. Wish us luck!

In this issue, you can read about our members' recent achievements, including searches for X-ray pulsations from neutron stars, OzGravvers commercialising technology for autonomous navigation, a new light projection exhibition, and your Director's appointment as a Fellow of the AAS.

Finally, we bid farewell to our brilliant Communications Officer Luana Spadafora, who has been the originator and editor-in-chief of Space Times. Lu has been a significant contributor to OzGrav, a valued team member, and we wish her all the best in her new role at RMIT.

Yours sincerely - Matthew Bailes (OzGrav Director)

NEWS IN BRIEF

- Congratulations to Distinguished Professor Susan Scott for being elected as Fellow of the International Society on General Relativity and Gravitation (ISGRG) for 2022 - the first Australian to receive this honour!
- Congratulations to our Director Matthew Bailes on being elected to the Fellowship of the Australian Academy of Science! More on page 10.
- Huge congratulations to Lyle Roberts and James Spollard (ANU), recipients of the first OzGrav Research Translation grant who since launched a start-up company (Vai Photonics) to further develop their technology for the autonomous navigation industry. More on page 6.
- Congratulations to OzGrav Chief Investigator Jade Powell (Swinburne) for being elected as co-chair of the LSC Burst group.
- Congratulations to OzGrav Associate Investigator Nikhil Sarin who was awarded the Robert Street Prize for the best PhD in the School of Physics and Astronomy.
- The 2022 OzGrav ECR workshop (21-22 Nov) and Retreat (23-25 Nov) will be held in Canberra. Please save the dates! Further details and registration will be announced soon.
- OzGrav will be hosting the Gravitational Wave Physics and Astronomy Workshop (GWPAW) from 5-9 Dec 2022. It will take place in Melbourne and online for remote participation. Preliminary information can be found on the GWPAW2022 website, and we will be regularly updating this with event details.
- OzGrav will be supporting The Supernovae in the Gravitational Wave Detection Era workshop that will take place at Swinburne University, Hawthorn campus, 28th Nov- 2nd Dec. More info here.

Editor-in-chief: Luana Spadafora
Subscribe here.

Background image by Carl Knox, OzGrav-Swinburne University

Deep Follow-up of GW151226: an ordinary binary or a low-mass ratio merger?

Now that we've been detecting gravitational waves (GWs), we'd like to better understand the systems that generate GWs. The GWs found so far have been from collisions of celestial bodies, like black holes and neutron stars. Once we have detected a GW, we use "Bayesian Inference" to deduce the masses and spins of the objects that shot off the GW (to understand inference, check this video by 3blue1brown). Then we can use our mass and spin deductions to answer: where do these bodies exist in the Universe? Are these colliding bodies huddled together in galaxies or isolated in space? But, it gets tricky to answer such questions if our deductions of the masses and spins are incorrect! So, in my recent study, I have built a "deep follow-up" tool to determine which masses and spins better describe a given GW event.

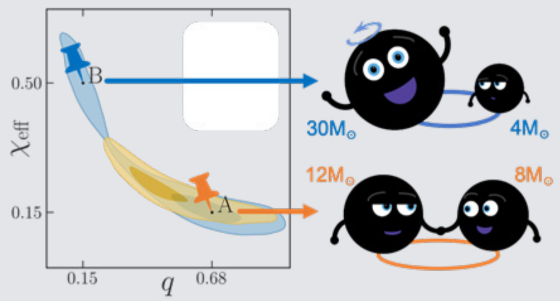


Figure 1: GW151226's dual identities. (Left) The initial and new Bayesian inference results are plotted in orange and blue, respectively. We perform a deep follow-up on the pinned points, cases A and B. (Right) Illustrative versions of what cases A and B represent. Note: black hole cartoons inspired by NASA's Field guide to black holes.

I have used this deep follow-up tool to study the "boxing-day" gravitational wave, GW151226. Initial work deduced that this GW was from the merger of two black holes (BHs), both with standard masses and spins (case A). However, recent work has deduced that the GW might have originated from a strange system: one BH could be much larger than the other and with a faster spin (case B)! A diagram representing these cases can be seen below on the right side of Figure 1.

Figure 1: GW151226's two personalities. (Left) The initial and new Bayesian inference results are plotted in orange and blue, respectively. We perform a deep follow-up on the pinned points, cases A and B. (Right) Illustrative versions of what cases A and B represent. Note: black hole cartoons inspired by NASA's Field guide to black holes.

The "deep follow-up" method involves drilling into these cases to determine which binary BH system better describes the GW. First, we pin down some deduced properties of the merging black hole system, such as the mass-ratio q (the ratio of smaller BH mass divided by the bigger BH mass) and xeff (the effective spin of the binary in the z-direction). The pinned value for the initial and new results is on the left side of Figure 1. We then use Bayesian inference at these pinned values. The output allows us to compare case A and case B. We find that both the standard (case A) and irregular (case B) black hole pairs can describe GW151226, giving the event something like a dual-identity!

This dual-identity gives GW151226 much more character than initially considered. For example, we initially believed that GW151226 came from an isolated black hole pair. However, a BH pair from case B is more likely to be found at the centre of an active galaxy! So, finally, I wonder: are there other GW events with dual identities? Hopefully, our deep follow-up method will be able to settle these questions.

Written by OzGrav researcher Avi Vajpeyi, Monash University.

Astronomers search for X-ray signposts of the elusive continuous gravitational waves

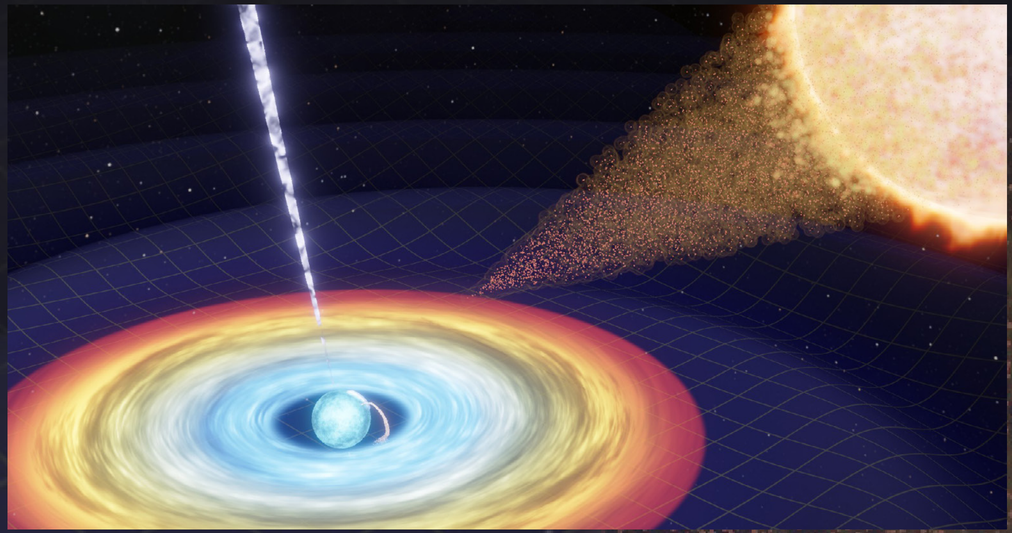
In the last few years, astronomers have achieved an incredible milestone: the detection of gravitational waves, vanishingly weak ripples in the fabric of space and time emanating from some of the most cataclysmic events in the Universe, including collisions betweens black holes and neutron stars. So far there have been over 90 gravitational-wave detections of such events, observable for only ~0.1 to 100 seconds. However, there may be other sources of gravitational waves, and astronomers are still on the hunt for continuous gravitational waves.

Continuous gravitational waves should be easier to detect since they are much longer in duration compared to signals from compact-object collisions. A possible source of continuous waves is neutron stars, which are stellar "corpses" left over from supernova explosions of massive stars. After the initial explosion, the star collapses in on itself, crushing atoms down into a super-dense ball of subatomic particles called "neutrons" - hence the name "neutron star". The continuous wave signal is related to how fast the neutron star is spinning, so precise measurements of the spin frequency using more conventional telescopes would greatly improve the chance of detection of these elusive waves.

In a recent study, led by OzGrav PhD student Shanika Galaudage from Monash University, scientists aimed to determine neutron stars' spin frequencies to help detect continuous gravitational waves.

Possible sources of continuous gravitational waves

In this study, researchers hypothesised that continuous gravitational-waves indirectly come from the gradual accumulation of matter onto a neutron star from a low-mass companion star–these binary systems of a neutron star and companion star are called low mass X-ray binaries (LMXBs).



Artist's impression of one potential source of continuous gravitational waves - Asymmetric accretion onto a spinning neutron star. Credit: Mark Myers, OzGrav-Swinburne University

If the neutron star can maintain an accumulated "mountain" of matter, (even if only a few centimetres in height!), it will produce continuous waves. The frequency of these waves relate to how fast the neutron star is spinning. The faster you accumulate this matter, the bigger the "mountain", producing larger continuous waves. Systems that accumulate this matter more quickly are also brighter in X-ray light. Therefore the brightest LMXBs are the most promising targets for detecting continuous waves.

Scorpius X-1 (Sco X-1) and Cygnus X-1 (Cyg X-2) are two of the brightest LMXB systems–Sco X-1 ranks second in X-ray brightness compared to the Sun. In addition to their extreme brightness, scientists know a lot about these two LMXB systems, making them ideal sources of continuous waves to study. But, their spin frequencies are still unknown.

"A way we can determine how fast these neutron stars are spinning is by searching for X-ray pulsations," says study lead Shanika Galaudage. "X-ray pulsations from neutron stars are like cosmic lighthouses. If we can time the pulse we would immediately be able to reveal their spin frequency and get closer to detecting the continuous gravitational-wave signal."

"Sco X-1 is one of the best prospects we have for making a first detection of continuous gravitational waves, but it's a very hard data analysis problem," says OzGrav researcher and study co-author Karl Wette, from The Australian National University. "Finding a spin frequency in the X-ray data would be like shining a spotlight on the gravitational wave data: 'here, this is where we should be looking'. Sco X-1 would then be a red-hot favourite to detect continuous gravitational waves."

Searching for X-ray pulsations

The team performed a search for X-ray pulsations from Sco X-1 and Cyg X-2. They processed over 1000 hours of X-ray data collected by the Rossi X-ray Timing Explorer instrument. The search used a total of ~500 hours of computational time on the OzSTAR supercomputer!

Unfortunately, the study did not find any clear evidence of pulsations from these LMXB sources. There are a number of reasons why this could be: the LMXB could have weak magnetic fields which are not powerful enough to support detectable pulsations. Or it could be that the pulsations come and go over time, which would make them hard to detect. In the case of Sco X-1, it could possibly be a black hole, which we would not expect to produce X-ray pulsations.

The study does find the best limits on how bright these X-ray pulsations could be if they did occur; these results could mean that neutron stars cannot sustain mountains of matter under its strong gravity. Future research can build on this study by employing better search techniques and more sensitive data.

Written by OzGrav researcher Shanika Galaudage (Monash University)

Published in MNRAS: Deep searches for X-ray pulsations from Scorpius X-1 and Cygnus X-2 in support of continuous gravitational wave searches

As featured in Phys.org.

OzGrav researchers shape the future of photonic sensing with spin-off company Vai Photonics

In 2021, Australian researchers Lyle Roberts and James Spollard, from The Australian National University (ANU), co-founded Vai Photonics: a spin-off company developing patented photonic sensors for precision navigation. OzGrav played a key role in kickstarting Vai Photonics by providing seed funding towards fundamental LiDAR research, which translated to real-world, industry applications. Now, Advanced Navigation, one of the world's most ambitious innovators in AI robotics and navigation technology, has announced the acquisition of Vai Photonics with aims to commercialise Roberts and Spollard's research into exciting autonomous and robotic applications across land, air, sea and space.

OzGrav reseearchers & co-founders Lyle Roberts and James Spollard

Vai Photonics co-founder James Spollard explained: "Precision navigation when GPS is unavailable or unreliable is a major challenge in the development of autonomous systems. Our emerging photonic sensing technology will enable positioning and navigation that is orders of magnitude more stable and precise than existing solutions in these environments.

"By combining laser interferometry and electro-optics with advanced signal processing algorithms and real-time software, we can measure how fast a vehicle is moving in three dimensions," said Spollard. "As a result, we can accurately measure how the vehicle is moving through the environment, and from this infer where the vehicle is located with great precision."

The technology, which has been in development for over 15 years at ANU, will solve complex autonomy challenges across aerospace, automotive, weather and space exploration, as well as railways and logistics. OzGrav Director Professor Matthew Bailes said he was thrilled to see such a positive outcome for our early career researchers that were supported by OzGrav's industry seeding scheme and workshops. "It reinforces the fact that pushing the limits of instrumentation for scientific purposes can often create opportunities for Australian innovators and industry," said Bailes.

Professor Brian Schmidt, Vice-Chancellor of the Australian National University said: "Vai Photonics is another great ANU example of how you take fundamental research – the type of thinking that pushes the boundaries of what we know – and turn it into products and technologies that power our lives.

Co-founders Lyle Roberts and James Spollard with ANU Vice Chancellor Brian Schmidt

"The work that underpins Vai Photonics' advanced autonomous navigation systems stems from the search for elusive gravitational waves – ripples in space and time caused by massive cosmic events like black holes colliding. The team have built on a decade of research and development across advanced and ultra-precise laser measurements, digital signals and quantum optics to build their innovative navigation technology. We are proud to have backed Vai Photonics through our Centre for Gravitational Astrophysics and business and commercialisation office. It's really exciting to see the team take another major step in their incredible journey," said Prof Schmidt.

Co-founder Dr Lyle Roberts looks forward to an autonomous future: "This is a huge win for the Vai Photonics team – together with Advanced Navigation we are able to bring our product to market much faster than originally planned. We now have access to leading research and development facilities along with strong distribution channels. We couldn't have asked for a better outcome and look forward to navigating the future with Advanced Navigation."

This acquisition fits into Advanced Navigation's larger growth strategy to expand its product and solutions portfolio across deep technology fields that look to solve the world's greatest challenges facing the autonomy revolution. The acquisition was finalised in April 2022, subject to typical closing conditions. The Vai Photonics team has been integrated into Advanced Navigation's research and development team, based out of the new Canberra research facility.

This article is an amended extract from the original article written by Laura Hayward published on www.advanced-navigation.com

Gravitational wave scientists develop new laser mode sensor with unprecedented precision

Lasers support certain structures of light called 'eigenmodes'. An international collaboration of gravitational wave, metasurface and photonics experts have pioneered a new method to measure the amount of these eigenmodes with unprecedented sensitivity.

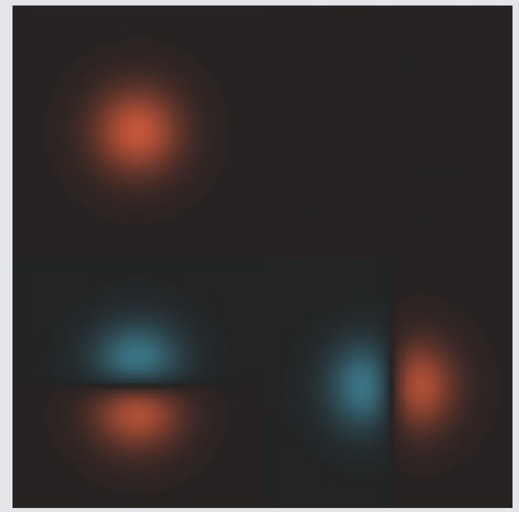


Figure 1 False colour image of laser eigenmodes that were tested. The colour indicates the phase of the light. Red is 0 degrees, blue is 180 degrees.

In gravitational wave detectors, several pairs of mirrors are used to increase the amount of laser light stored along the massive arms of the detector. However, each of these pairs has small distortions that scatters light away from the perfect shape of the laser beam. This scattering can cause excess noise in the detector, limiting sensitivity and taking the detector offline.

From the recently submitted study, Prof Freise (from Vrije Universiteit Amsterdam) says: "Gravitational wave detectors like LIGO, Virgo and KAGRA store enormous amount of optical power – in this work, we wanted to test an idea that would let us zoom in on the laser beam and look for the small wiggles in power that can limit the detectors' sensitivity."

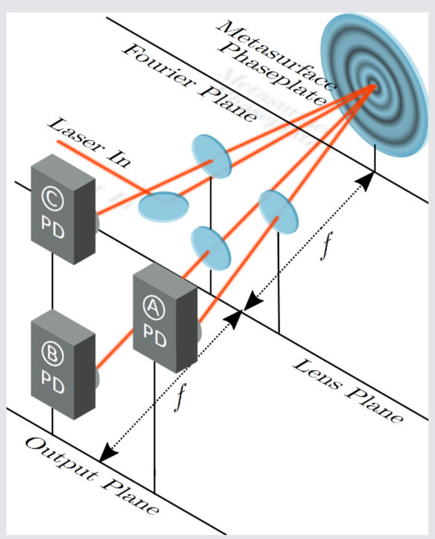


Figure 2 A schematic of the apparatus used by the researchers. f is the focal length of the lens

A similar problem is encountered in the telecoms industry where scientists want to use multiple eigenmodes to transport more data down optical fibres. OzGrav researcher and lead author Dr Aaron Jones (The University of Western Australia) explains: "Telecoms scientists have developed a way to measure the eigenmodes using a simple apparatus, but it's not sensitive enough for our purposes. We had the idea to use a metasurface and reached out to collaborators who could help us fabricate one."

In the study, the proof-of-concept setup the team developed was over 1000x more sensitive than the original way developed by the telecoms scientists. The researchers will now look to translate this work into gravitational wave detectors, where the additional precision will be used to probe the interiors of neutron stars and test fundamental limits of general relativity.

OzGrav Chief Investigator, Prof Zhao (from University of Western Australia) says: "Solving the mode sensing problem in future gravitational wave detectors is essential, if we are to understand the insides of neutron stars."

Written by Dr Aaron Jones (The University of Western Australia)

Background image by Carl Knox, OzGrav-Swinburne University

RESEARCH HIGHLIGHT

The High Time Resolution Universe Pulsar Survey

Double neutron star (DNS) systems in tight orbits are fantastic laboratories to test Einstein's general theory of relativity. The first such DNS system, commonly known as Hulse-Taylor binary pulsar, provided the first indirect evidence of the existence of gravitational waves and the impetus to build LIGO. Since then, discovering such binary systems has been a major impetus for large scale pulsar surveys. Although over 3000 pulsars have been discovered in our Galaxy, we have only found 20 DNS systems. Why are they so rare?

DNS systems are the endpoints of complex and exotic binary stellar evolution. In the standard model, the two stars must survive multiple stages of mass transfer, including common envelope phases, and not one but two supernova explosions. Prior to the second supernova, the survival of the binary depends on the kicks imparted by the second supernova explosion and the amount of matter ejected. It appears that it's quite rare for binaries to survive all of these events. Those that do leave behind many insights into binary stellar evolution.

Finding binary pulsars is more difficult than solitary ones. Acceleration makes their pure tones evolve in time due to the changing Doppler shifts, greatly increasing the complexity of the searches and the amount of computational time required. Fortunately, OzGrav scientists have access to the OzSTAR supercomputer at Swinburne University of Technology with its graphics processing accelerators (GPUs). We use OzSTAR to search the High Time Resolution Universe South Low Latitude pulsar survey (HTRU-S LowLat) for accelerated pulsars. In our recently accepted paper, we have presented the discovery and results from 1.5 years of dedicated timing of a new DNS system, PSR J1325-6253 using the Parkes 64m radio telescope (now also known as Murriyang).

By timing when the pulses arrived at Earth, we found that PSR J1325-6253 is in a small orbit of 1.81 d. Its orbit deviates from a circularity with one of the lowest orbital eccentricities known for a DNS system (e=0.064). The elliptical orbit advances its point of closest approach (periastron) to its companion star as predicted by the theory of general relativity. The advance of periastron enabled us to determine the total mass of the system, and we found it near that of other DNS systems. The low eccentricity of the orbit meant that there was almost no mass loss in the final supernova explosion beyond the energy carried off in neutrinos, and that it was a so-called ultra-stripped supernova. Such supernovae would be very sub-luminous, and usually invisible if too far from the Sun. This rare find provided a new insight into how stars explode, and the neutron stars they leave behind.

Written by OzGrav PhD student Rahul Sengar, Swinburne University of Technology

OzGrav Director Prof Matthew Bailes elected Fellow of the Australian Academy of Science

Pioneering astrophysicist and OzGrav Director Professor Matthew Bailes has been recognised for his outstanding contributions to science by being elected a Fellow of the Australian Academy of Science. Professor Bailes has specialised in the study of pulsars, fast radio bursts and gravitation, making major contributions to establishing Australia's high international profile in these areas.

In particular, he has played a pivotal role in the development of a new branch of astrophysics, Fast Radio Bursts, developing pioneering instrumentation and software that led to Australia's early dominance of the field. Professor Bailes has been central in putting Swinburne University of Technology at the cutting-edge of astrophysics.

Centre for Astrophysics and Supercomputing

In 1998 he established Swinburne's Centre for Astrophysics and Supercomputing, recognised internationally as a centre for astrophysics and virtual-reality content for public outreach. The centre hosts one of Australia's most powerful supercomputers and has developed 3D virtual reality films for its custom 3D theatres and IMAX.

The centre has graduated over 100 PhDs and pioneered online education via Swinburne Astronomy Online, but also worked with many school children for work experience and virtual tours of the Universe in their custom 3D theatre.

ARC Centre for Excellence for Gravitational Wave Discovery (OzGrav)

In 2016 Professor Bailes was appointed the Director of the Australian Research Council Centre for Excellence for Gravitational Wave Discovery (OzGrav). Hosted at Swinburne OzGrav is a worldwide collaboration that aims to understand the extreme physics of black holes and warped space time.

Professor Bailes was named among 22 outstanding researchers from across the breadth of Australian science as a Fellow of the Academy.

Upon hearing the news of his election Professor Bailes said: "I've always had a burning desire to understand how the Universe works and want to thank my mentors, staff, collaborators and students for enabling the discoveries I've been involved with." He nominated the discovery of the Fast Radio Bursts as his career highlight. "I couldn't sleep the night after the first one was discovered because it seemed too good to be true! Fortunately, it was true."

Incoming President of the Australian Academy of Science Professor Chennupati Jagadish AC, congratulated the new Fellows for their contributions to science. "Fellows of the Australian Academy of Science are among the nation's most distinguished scientists, elected by their peers for ground-breaking research and contributions that have had clear impact," Professor Jagadish says. "We reflect a diverse and inclusive science community that recognises the widest range of talents, backgrounds, perspectives and experiences, and we are united by our contribution and commitment to scientific excellence."

This article is an amended version of the media release originally publish on Swinburne University's website.

Rippling gravitational waves and space-time projections at the Firelight Festival!

OzGrav EPO Artist Carl Knox recently created amazing space-time projections for the Firelight Festival in early July at the Docklands in Melbourne. The rippling gravitational waves were both mesmerising and educational. Great work Carl – we can't wait to see what's next!

The projections were a collaboration with Ozgrav and Renew Australia.

Background image by Carl Knox, OzGrav-Swinburne University

OzGrav researcher Valentina Di Marco

When I was a kid, I was always in trouble. So, one day, my parents had to come all the way to school camp to pick me up as I did something surely terrible and disruptive, I cannot really remember what, and the teachers wanted me out of there. My dad told me to wait in the car while he went to talk to my teachers. The car had a roof window, and we were at a good altitude far from big cities and light pollution, in the Swiss Alps. I was in the passenger seat playing with the electric chair recliner and there it was, the milky way! Bright and beautiful, like a river made of millions of tiny lights. I knew then that I wanted to be a scientist. I was nine years old.

A few years later, after graduating from an art lyceum (lots of painting and sculpting), I started my degree in physics at the University of Milano Bicocca. During this time, I discovered that mathematics is not the dull exercise that they sometimes teach in secondary school, but there is much beauty in it. Alas, I also discovered money and the freedom that comes with it. I was lucky enough that my first "grown up job" was paying OK and was interesting, so I deep dived into it.

After much travelling around the world, moving from my native country (Italy) to Ireland, getting married, having 3 kids, and building a career in digital marketing, I decided to go back to my books and completed an honours degree in mathematics at Technological University Dublin. But, while Ireland is a wonderful country, I was way too cold there, so I was more than happy to move to Australia with my family when the opportunity arose.

I was not done with studying though. In 2018 I started a Master of Philosophy in statistics at Monash University (because, you know, maths), which I completed recently, and that led me to starting a PhD in Astrophysics where I could apply my knowledge of statistics to the study of gravitational waves. I came full circle from that evening in the Alps when I was nine years old.

In my research, I try to improve existing detection methodologies of gravitational waves generated by supermassive black holes dancing around each other. I currently work on a project focussing on how the use of wrong models can lead to false detections of gravitational waves in millisecond pulsars experiments.

I am a big advocate of diversity in science and believe there is still much work to do to bring equality between genders in any field. From my very own experience, I am painfully aware of how hard it still is to work full time as a mother or having a career as a woman.

My website: https://vdmwebsites.wixsite.com/valentinadimarco

Do massive-star models from various simulations give the same predictions?

Less than one percent of stars in a galaxy are formed with masses exceeding ten solar masses. Despite their rarity, massive stars are believed to play a crucial role in shaping their surroundings, ultimately determining the evolution of the star cluster or galaxy they are located in.

Figure 1: The 30 Doradus nebula in the Large Magellanic Cloud is home to many massive stars. Credit: NASA/ESA

Simulations of massive stars are used in many fields of astrophysics, from predicting gravitational-wave event rates to studying star formation and star cluster evolution. However, their rarity and short lives, along with their more extreme properties, mean that the evolution of massive stars is riddled with many uncertainties. These uncertainties are compounded by the fact that accurate modeling of stellar lives in three dimensions is prohibitively expensive in terms of computing resources.

Therefore, stellar evolution is modeled using one-dimensional (1D) codes, with only radius or mass as the spatial coordinate. Three-dimensional (3D) processes such as rotation and mixing are approximated using 1D analogs, which generally give good results for most stars. However, in the envelopes of massive stars (and in low-mass stars at the late stages of evolution), the use of these 1D analogs can lead to numerical challenges for stellar evolution codes. The time steps of the computation become very small (of the order of days) and 1D codes struggle to compute the further evolution of the star.

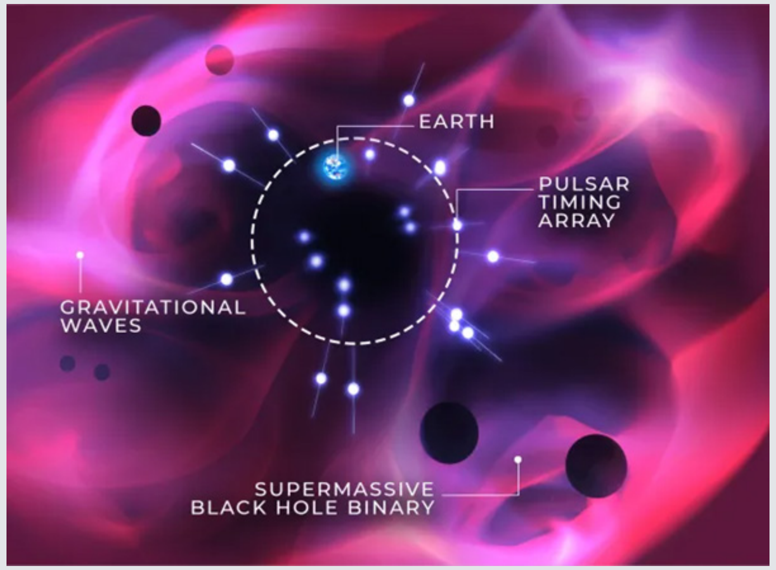
While researchers are trying to find the solution using multidimensional models, 1D stellar evolution codes adopt different pragmatic methods to push the evolution of stars beyond these numerical challenges. These methods, along with other uncertain parameters in the evolution of massive stars, can significantly alter the predictions of massive stellar models. To get an idea of how different their predictions can be, we examined models of massive stars from five different datasets, each computed using a different 1D code.

We found that certain aspects of these predictions were extremely sensitive to the modeling assumptions employed by different codes. We also found huge differences in the radial evolution of these stellar models and thus the ionizing radiation produced by them. These differences can directly affect binary evolution and the simulations of stellar environments, such as galaxies.

While different astrophysical studies focus on different aspects of stellar populations, stellar evolution is inherently basic to most of them. It is therefore important to determine and characterise the uncertainties resulting from the evolution of single stars. Any study that uses models of massive stars should also account for their physical and numerical uncertainties.

Link to recently published study: https://arxiv.org/abs/2112.02800.
Written by OzGrav Affiliate Dr Poojan Agrawal, Carnegie Mellon Pittsburgh, USA.

Scientists predict gravitational waves from merging supermassive black holes



At the centre of most galaxies there is a massive black hole. These black holes are very heavy – their mass can be from a million to over a billion times the mass of the Sun and, as such, are appropriately known as supermassive black holes. As galaxies move around in the Universe, they will sometimes merge. When this happens, the supermassive black holes they host tend to migrate toward each other and form a binary system. As these two black holes orbit each other, they warp the fabric of space and time around them and produce gravitational waves which ripple out into the Universe. These gravitational waves complete one full oscillation every year or so as they travel through space and are classified as low frequency gravitational waves.

The Universe is full of these supermassive black hole binary systems, and the gravitational waves they emit fill space, combining to form something known as the stochastic gravitational wave background. Scientists are trying to find a gravitational wave signal from this background using a complex network of radio telescopes called a pulsar timing array but it could be years before there is a confirmed detection.

For this reason, cosmological simulations are often used to predict what this gravitational wave signal could look like. This type of simulation helps scientists understand the structure and history of the Universe by tracking the flow of matter and energy from a time soon after the Big Bang, up until today.

A team of researchers led by postgraduate researcher Bailey Sykes (from Monash University), alongside several OzGrav scientists, including OzGrav Associate Investigator Dr Hannah Middleton, have recently made a new prediction for the strength of this gravitational wave signal. The new estimate is based on data from the MassiveBlack-II simulation, which simulates a massive region of space similar to a chunk of our own Universe.

The team made two estimates: one in which the supermassive black holes merge almost instantly once their host galaxies collide, and another in which the two black holes take time to sink towards each other once they pair up in a binary system. This second estimate is important as the gravitational wave output of a binary can change during this time due to the interactions of stars and gas nearby the supermassive binary.

The simulated gravitational wave signal using MassiveBlack-II is similar to other predictions in previous studies. It's smaller than a signal currently detectable by pulsar timing arrays; however, as the sensitivity of telescope technology increases over time, it's possible a confirmed detection could be just around the corner.

The results from the study add valuable insights to existing signal predictions and provide an important reference point for future pulsar timing arrays. Progressively more accurate estimates of the stochastic gravitational wave background can be used to further understand other astrophysical phenomena, including the interactions of stars and gas which impact merging supermassive black holes.

Written by Bailey Sykes (Monash University)

About OzGrav

The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) is funded by the Australian Government through the Australian Research Council Centres of Excellence funding scheme. OzGrav is a partnership between Swinburne University of Technology (host of OzGrav headquarters), the Australian National University, Monash University, University of Adelaide, University of Melbourne, and University of Western Australia, along with other collaborating organisations in Australia and overseas.

The mission of OzGrav is to capitalise on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime, and to inspire the next generation of Australian scientists and engineers through this new window on the Universe.

OzGrav is part of the international LIGO-Virgo collaboration. LIGO is funded by NSF and operated by Caltech and MIT, which conceived of LIGO and led the Initial and Advanced LIGO projects. Financial support for the Advanced LIGO project was led by the NSF with Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council) and Australia (Australian Research Council-OzGrav) making significant commitments and contributions to the project. Nearly 1300 scientists from around the world participate in the effort through the LIGO Scientific Collaboration. The Virgo Collaboration is composed of approximately 350 scientists from across Europe. The European Gravitational Observatory (EGO) hosts the Virgo detector near Pisa in Italy, and is funded by Centre National de la Recherche Scientifique (CNRS) in France, the Istituto Nazionale di Fisica Nucleare (INFN) in Italy, and Nikhef in the Netherlands.

The Kamioka Gravitational Wave Detector (KAGRA), formerly the Large Scale Cryogenic Gravitational Wave Telescope (LCGT), is a project of the gravitational wave studies group at the Institute for Cosmic Ray Research (ICRR) of the University of Tokyo. It will be the world's first gravitational wave observatory in Asia, built underground, and whose detector uses cryogenic mirrors. The design calls for an operational sensitivity equal to, or greater, than LIGO. The project is led by Nobelist Takaaki Kajita who had a major role in getting the project funded and constructed.

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